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COMPOSTING OF STABILIZED MUNICIPAL SEWAGE SLUDGE WITH RESIDUES FROM AGRI-FOOD PROCESSING IN POLAND

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ABSTRACT: Stabilized municipal sewage sludge and selected waste from agri-food processing can be used for agricultural purposes, which is part of the circular economy. Therefore, chosen residues were tested for the possibility of using them for fertilisation purposes. They were then subjected to the process of composting in a bioreactor with artificial aeration. The compost mixtures were prepared to take into account their contents of, among others, carbon, nitrogen, phosphorus, and water; in the case of sewage sludge, the contents of biological contaminants and heavy metals were also determined. Based on the conducted studies, it has been found that organic waste from agri-food processing and stabilised municipal sewage sludge can be used in the composting process. At the same time, the obtained compost is characterised by good fertilising properties. Considering the physicochemical properties of the obtained compost, it was found that it can be a precious fertiliser used as a soil additive.

KEYWORDS: compost, fertilisation, agri-food processing, sewage sludge

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Introduction

The issue of sewage sludge management is one of the priority tasks in wastewater management. One of the ways of managing this type of waste is composting, i.e. a natural and environmentally friendly method resulting in a high-quality end product in the form of a fertiliser or soil improver (Brod et al., 2012; Kootenaei et al., 2014). Sewage treatment is accompanied by the formation of sewage sludge, the stabilisation and management of which is an increasingly significant financial burden for water and sewage companies. The amount of sewage sludge produced results directly from a load of pollutants on the sewage treatment plant (Klaczyński, 2020). Production of sewage sludge is a continuous process which gives constant access to manageable waste. Producers of sewage sludge are willing to dispose of the material as national, and EU laws prohibit sewage sludge storage (Nedelciu et al., 2019; Rosiek, 2020). However, it should be remembered that composting of sewage sludge must be carried out in accordance with the conditions specified in the decision on waste treatment in the R3 recovery process (Regulation, 2015). It is currently observed that the construction of new sewage treatment plants and the modernisation and expansion of the existing ones is leading to increasing amounts of municipal sewage sludge, which requires management (Sogn et al., 2018; Ding et al., 2021). This increase in the mass of generated sewage sludge observed in recent years, and the prohibition of its storage make the management of municipal sewage sludge a significant environmental, technical, and economic problem (Bień et al., 2011).

According to the Strategy for the Treatment of Municipal Sludge in Poland for 2019-2022 developed by the Ministry of Environment (2018), one of the recommended management methods is to use it for fertilisation purposes in the composting process. However, applying municipal sewage sludge on the ground is only possible under conditions imposed by the waste legislation. The purpose of municipal sewage sludge recovery on the Earth's surface is to make use of its valuable agronomic properties and fertilising potential, i.e. the organic matter and the nutrients needed by plants, such as nitrogen (N), phosphorus (P), and microelements contained in it. Additionally, it should be emphasised that an essential element of the composting process is control of the composition of the compost mixture. This contributes to a stable and environmentally safe product (Lu et al., 2009). Meeting the quality criterion and ensuring that the correct process conditions are in place makes it possible to obtain a high-quality product. However, to ensure the desired product quality, it is estimated that the share of sediment in the compost mass should not exceed approx. 30% by weight (Stürmer & Waltner, 2021). Therefore, composting sewage sludge is only possible with other substrates. It seems

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that the best solution would be to add organic waste from agri-food processing, characterised by the appropriate physicochemical properties (including in terms of fertilisation), which would allow us to obtain a compost mixture with suitable characteristics (including the C:N ratio). A proper selection of raw materials and parameters of the composting process would make it possible to obtain a product with the best fertilising properties, one that would be safe for the environment (Liu et al., 2020). Taking the above into account, it is possible to obtain a product (fertiliser or plant conditioner) meeting the criteria for placing it on the market according to the provisions on fertilisers and fertilisation.

The management of organic residues (sewage sludge, waste) for fertilisation purposes is an important issue due to the contents of fertilising components in soils in Poland. Data obtained from the Central Statistical Office (GUS, 2019) indicates that the availability of macronutrients such as phosphorus, magnesium, and potassium in Poland in the years 2015-2018 is low or medium. Therefore, composted sludge and organic waste can constitute undisputed sources of these components. Furthermore, given that today's agriculture relies on the use of mineral fertilisers to provide nutrients to crops and that global resources of fossil fuels and phosphate, i.e. the raw materials used for the production of mineral fertilisers, are depleting, they need to be replaced by another source of nutrients to ensure food security in the future. This deficit can be rectified by using waste from agri-food processing plants and sewage sludge, i.e. extensive sources of humus-forming organic matter and nutrients needed by plants while composting these resources into valuable and safe fertilisers restore the soil's value (Piwowar, 2013). In addition, it should be noted that the management of sewage sludge and waste from agri-food processing is part of Poland's environmental policy and the concept of circular economy, which has been a priority in European Union countries since 2015 (Sulewski et al., 2021). In addition, considering the current social and economic situation in Poland and other European Union countries, attention should be paid to the increasing prices of mineral fertilisers and their availability. Therefore, it is advisable to look for solutions that would meet the fertilisation needs of agriculture.

Mixing various types of waste in order to improve the conditions of composting processes would allow obtaining a product that meets the requirements of the Act on Waste; the resulting final product can be used for environmental purposes, which is of great ecological value, favouring the improvement of sludge management in sewage treatment plants and the circular economy. Hence, this study aimed to assess the possibility of using stabilised municipal sewage sludge in a composting process with residues from agri-food processing.

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The study aimed to examine whether stabilised municipal sewage sludge and selected waste from agricultural and food processing can be used for agricultural purposes. Selected residues were examined for the possibility of their application for fertilisation purposes; then, they were subjected to a composting process in a bioreactor with artificial aeration. The compost mixtures were prepared so that attention was paid to the contents of carbon, nitrogen, phosphorus, and water. In the case of sewage sludge, biological pollutants and the content of heavy metals in the soil were also determined.

Research methods

The research material consisted of stabilised municipal sewage sludge and selected residues from agri-food processing obtained from plants operating in the Podlaskie Voivodship. In order to prepare a suitable compost mixture, laboratory analyses were carried out to determine the basic properties of the substrates. These tests included, among others, the determination of nitrogen (N) and carbon (C) contents in order to calculate the C: N ratio, a knowledge of which is essential for the preparation of the compost mixture. Based on these determinations, the following biodegradable waste types were selected for further analysis (according to the types of waste included in the Regulation of the Minister of Climate of 2 January 2020 on Waste Catalogue):

- waste plant mass,
- pomace, sludge and other waste from the processing of plant products,
- biodegradable kitchen waste,
- biodegradable garden and park waste.

The examined waste is food scraps obtained from selective waste collection, i.e. the so-called biodegradable kitchen waste and fruit processing pomace. In addition, waste from gardens and parks, i.e. urban landscaping, harvest residues such as straw and hay, and organic waste from urban markets representing, among others, vegetable and fruit residues and leftovers, were used as a structural substrate. According to the requirements for composting and the National Waste Management Plan 2022 (2016) applicable in Poland, the waste in question is biodegradable and can be used for compost production. Tests of stabilised municipal sewage sludge were carried out using reference testing methods specified in the Regulation of the Minister of the Environment of 6 February 2015 on Municipal Sewage Sludge (Table 1).

In order to determine the selected physicochemical properties of waste and compost, methods regarding pH, dry and organic matter contents, and nitrogen and total phosphorus contents specified in Table 1 were used. Moreover, the content of organic carbon was determined using the catalytic combustion method, and the content of potassium using a flame photometer.

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Table 1. List of reference research methods

Indicator	Method
pH	potentiometric determination in aqueous solution
dry matter content	drying at 105°C, weighing
organic matter content	roasting at 600°C, weighing
total nitrogen content	acid digestion with addition of catalyst
total phosphorus content	mineralization to phosphorus (V) and spectrophotometric determination
calcium and magnesium content	digestion with acid mixture and determination by atomic spectrometry
heavy metal content: lead, cadmium, mercury, nickel, zinc, copper and chromium	atomic absorption spectrometry after digestion in concentrated acids
presence of pathogenic bacteria of the genus *Salmonella*	culture on multiplex and differential selective media
number of live eggs of intestinal parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp.	isolation of live eggs from a representative sample of the sediment and microscopic examination

Based on the determined nitrogen and carbon contents in the composted substrates, the C: N ratio was calculated, which allowed determining the optimal composition of the mixture intended for composting. The first phase of the composting process was carried out in a laboratory bioreactor with a capacity of 30 dm^3 and aeration of 3 dm^3/min (Figure 1).

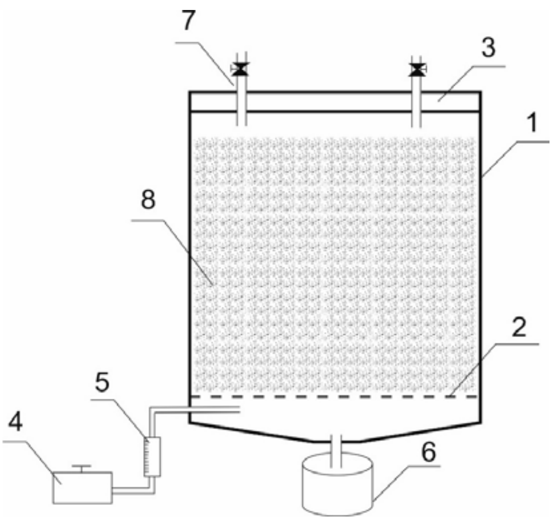

Figure 1. Diagram of the laboratory bioreactor:
1 – enclosure, 2 – perforated bottom, 3 – sealed cover, 4 – air pump, 5 – flow meter, 6 – leachate container, 7 – air vents with air flow regulation, 8 – composted biomass

With the correct operation of the bioreactor, the temperature was about 70˚C, and the decomposition of the matter was very intensive. This was followed by intense decomposition of the organic matter, decreasing over time, resulting in a successive drop in temperature down to 35˚C. After 14 days, fresh compost was placed on a heap. The compost heap was turned once a week, and the finished compost was obtained after 8 weeks.

Research results

Properties of stabilised municipal sewage sludge

Based on the laboratory analyses, it was found that the tested stabilised municipal sewage sludge is safe in terms of sanitation, and the content of heavy metals indicates that it can be used in agriculture. Moreover, based on selected physicochemical properties, it was found that the sludge has good fertilising properties (Table 2).

Table 2. Physical, chemical, and biological properties of the tested stabilised municipal sewage sludge

Indicator	Unit	Result
pH	-	7.8
dry matter	%	17.0
organic matter	% d.m.	57.6
total nitrogen	% d.m.	4.0
total phosphorus	% d.m.	2.9
calcium	% d.m.	6.4
magnesium	% d.m.	0.5
lead	mg/kg d.m.	20.5
cadmium		1.8
mercury		0.4
nickel		12.0
zinc		621
copper		154
chromium		17.2
presence of pathogenic bacteria of the genus *Salmonella*	-	not detected in 100g
number of live eggs of intestinal parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp.	pcs/kg d.m.	0

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The pH value of the tested stabilised municipal sewage sludge is alkaline. According to the literature, pH can range from 5 to 9, influenced by the quality of wastewater, the treatment methods, and the season when the parameter is tested (Bauman-Kaszubska & Sikorski, 2014; Maćkowiak, 2000). On the other hand, the content of organic matter of approx. 58% suggests that sewage sludge has a high potential for being used for agricultural, i.e. fertilisation purposes (Kazanowska & Szaciło, 2012; Singh & Agrawal, 2008). The contents of nitrogen, phosphorus, calcium, and magnesium compounds, i.e. those components that determine the fertilising value, indicate the possibility of using the tested sludge to produce compost. Moreover, among the properties tested, the content of impurities is an important issue. The performed tests show that the contents of all heavy metals do not exceed the values permissible in Poland, as specified in the Regulation of the Minister of the Environment of 6 February 2015 on Municipal Sewage Sludge. Therefore, the results of this research confirm that it can be used for the production of compost due to its not being contaminated with heavy metals; in addition, neither pathogenic bacteria nor live intestinal parasite eggs were found in it. Hence, the tested sewage sludge is characterised by good fertilising properties; it also constitutes a suitable raw material for compost production.

Composition of the fertiliser mixture

In order to determine the composition of the compost mixture, tests were carried out to establish the carbon and nitrogen contents of selected food processing waste. On this basis, the C: N ratio was calculated, allowing to determine the optimal composition of the mixture for composting (Table 3; Figure 2).

Table 3. Carbon (C) and nitrogen (N) contents in the analysed waste

Type of waste	C [%]	N [%]	C:N
municipal stabilized sewage sludge	33	4	9
waste plant mass	86	1.5	61
pomace, sludge and other wastes from the processing of plant products	18	2	11
biodegradable kitchen waste	52	2	28
biodegradable garden and park wastes	74	1.5	51

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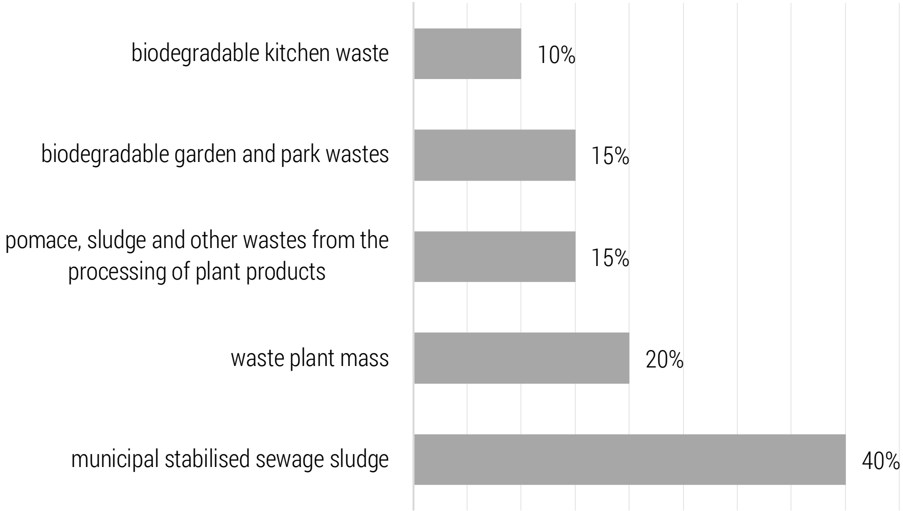

Figure 2. Composition of the compost mixture

Properties of the obtained compost

As a result of the composting process, fully mature compost was obtained, i.e. an organic fertiliser that can benefit soil fertility. The compost was characterised by its dark brown colour, uniform structure, and the peculiar smell of fresh soil. Table 4 shows the results of determining the fertilising properties of the finished compost obtained in laboratory tests.

Table 4. Physicochemical properties of the compost (mean value ± standard deviation)

Indicator	Unit	Result
pH	–	7.6 ± 0.4
dry matter	% d.m.	60 ± 2.3
organic matter		52 ± 1.8
N		1.70 ± 0.3
P		0.5 ± 0.1
K		1.25 ± 0.2
Ca		2.90 ± 0.7
Mg		0.50 ± 0.1

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The compost, with a 40% content of stabilised municipal sewage sludge and organic waste, has good fertilising properties. In the course of the study, it was found that the pH of the obtained mature compost was about 7, which indicates its neutral character. Compost from sewage sludge obtained by Radziemska et al. (2021) was also characterised by a reaction close to neutral. A study by Bożym and Siemiątkowski (2018) and another by Curci et al. (2020) showed the pH of composts to be around 7. Such a value of pH is favourable for compost's use under crops. Given that most soils in Poland are characterised by the acid reaction, using such a fertiliser would not worsen the soil reaction (Rutkowska, 2018). An appropriate dry matter content, and thus also its moisture content, is conducive to the decomposition of organic matter in the soil. In addition, the obtained compost was characterised by an organic matter content exceeding 50%, thus meeting the requirements for organic fertilisers. According to the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 on the Implementation of Certain Provisions of the Act on Fertilizers and Fertilization, the content of organic matter in composts should amount to at least 30% of organic matter on a dry matter basis. Studies conducted by other authors have also shown that the organic matter content of composts can exceed 50% (Bożym & Siemiątkowski, 2018). In the case of the obtained compost, the contents of nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium, i.e. those elements that affect the suitability of organic fertilisers for fertilisation, indicate good fertilising properties. The nitrogen content of the obtained compost was 1.7% d.m., whereas, in a study conducted by Bożym et al. (2014), the full content of this component was approx. 0.9%.

In studies conducted by other authors, the phosphorus content was similar to the values obtained in this study, i.e. 0.462% in the case of green waste compost (Wei et al., 2015) and 0.451% for one-year compost (Bożym et al., 2014). According to Gorlach and Mazur (2002), the phosphorus content of cattle manure is 0.28%, which makes the compost obtained in this study richer in phosphorus. Studies conducted by other authors have also shown that sewage sludge compost can be a good source of phosphorus (Stürmer & Waltner, 2021). In addition, the potassium content is also similar to that obtained in a study conducted by Bożym et al. (2014), where it was 1.24% and 1.21% for one- and two-year compost, respectively. However, according to Gorlach and Mazur (2002), sheep manure is the richest in potassium, containing 1.19% of the component. The higher potassium content of the tested compost compared to manure means that the resulting fertiliser has the potential to be used as an organic fertiliser to supplement potassium deficiencies in the soil. In addition, the compost had a high calcium content. In a study by Czop and Żydek (2017), green waste compost contained only 0.69% calcium. The high content of this element results in the resulting

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fertiliser having many valuable properties, such as reducing the soil's acidity, creating a favourable environment for the growth of soil bacteria, and improving the air and water conditions of the soil (Czop & Żydek, 2017).

On the other hand, the content of magnesium is within the range reported by Wasiak et al. (1999), who determined that the content of this component in various composts ranges from 0.36 to 1.41%. The magnesium content in manure is only 0.1%, and given that magnesium is an essential component in plant nutrition and its deficiencies are found in Polish soils, fertilisation with the use of the resulting compost can have a beneficial effect on plant growth and yield (Mazur, 2002). As research by other authors has shown, sewage sludge and compost obtained from it are characterised by good fertilising properties and are rich in fertilising ingredients (Ghulam et al., 2012; Kirchmann et al., 2017; Moretti et al., 2015).

However, it should be remembered that the contents of the individual nutrients necessary for the development of plants and microorganisms in the soil are influenced by the quality of the substrates used in the composting process (Bożym & Siemiątkowski, 2018; Uçaroğlu & Alkan, 2016). At the same time, this translates into the quality of the finished product (compost), whose physicochemical properties affect the course of the processes in the soil environment and stimulate plant growth (Gorlach & Mazur, 2002). Therefore, considering the chemical composition of the resulting compost, it was concluded that it could be an unquestionable source of nutrients for plants.

Conclusions

In order to obtain the finished product, i.e. an organic fertiliser (compost), the most efficient composting method was used in the study (two-stage – container), performed in a bioreactor. Composting of bio-waste in closed reactors is accelerated by optimising aeration, hydration, and process temperature control. Hence, the method in question is the most effective and fastest due to the possibility of controlling the process conditions. Controlled temperature and humidity enable the intense processes of biochemical decomposition of organic mass with the participation of aerobic fermentation (with an optimal air supply). Heat thus generated (up to 70ºC) accelerates the growth of mesophilic and thermophilic microorganisms, which is related to the hygienization of the compost mass. This phenomenon is essential for the composting of sewage sludge.

When preparing compost mixtures, particular attention was paid to the physical, chemical, and biological properties of waste used as substrates for compost production. Based on these studies, it was found that stabilised sew-

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age sludge has good properties and is not contaminated with heavy metals. Therefore, it could serve as a substrate for compost production. In addition, based on the calculated C:N ratio, the best proportion of waste in the compost mixture was determined, i.e. the content of the tested sewage sludge should be 40%.

Compost produced from sewage sludge and organic waste from agri-food processing was characterised by high contents of organic matter, nitrogen, phosphorus, potassium, calcium, and magnesium, which made it helpful in fertilising. Therefore, a fertiliser was obtained that meets the requirements for this type of product and can be used to improve the properties of soils.

In connection with the above, based on the conducted research, compost was obtained from stabilised municipal sewage sludge with an organic waste content, which is part of the areas of innovative technologies of waste treatment using biological and physical methods and the area of neutralisation of sewage sludge with organic co-substrates constituting organic waste. In addition, waste management for fertilisation purposes is part of the circular economy and the national waste management plan, as under Art. 14 of the Act of 14 December 2012 on Waste, in force in Poland, waste used for the production of compost ceases to be waste, and becomes a substrate for the recovery-composting process.

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The contribution of the authors

Małgorzata Krasowska – concept, literature review, acquisition of data, analysis and interpretation of data – 33.33%.

Małgorzata Kowczyk-Sadowy – concept, literature review, acquisition of data, analysis and interpretation of data – 33.33%.

Sławomir Obidziński – concept, literature review, acquisition of data, analysis and interpretation of data – 33.33%.

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